On the absorption of water by the green parts of plants.

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Notwithstanding many experiments, the question as to whether land plants absorb any considerable quantities of water through their green parts is still unsettled. It is to be noticed that the two extremes of absorption, i. e., the absorption of the major part of the water supply on the one hand, and of extremely minute and physiologically unimportant portions on the other, are here not brought into discussion. The first is settled beyond all doubt in the negative, and the second is of comparatively little importance and appears to be beyond any of the methods of investigation yet applied to it. But to know whether plants can under any normal conditions absorb water through green parts to an extent sufficient to profitably supplement the root supply, is of much general interest, even though, as a side question upon which nothing of consequence depends, it is of no great scientific moment.

The belief in the affirmative of the problem is very old and wide-spread, perhaps indeed nearly universal among gardeners and others dealing in a practical way with living plants. Its principal basis is the familiar fact that plants drooping through loss of water by too rapid transpiration revive if sprayed in the ordinary fashion. But if the conditions of this spraying be controlled and varied by experiment, the relationship of cause and effect is found to be quite different from that which is apparent. If (as has incidentally happened in some of the experiments presently to be described) the water be kept from the roots and the damp atmosphere created by the spray be soon removed, the plant does not revive. Or if the damp atmosphere be retained and the plant revives, its weight is found not to have increased, but rather diminished, as the following shows:

Exp. a. Healthy young *Ricinus*, the pot and earth wrapped in rubber cloth, was kept in a dry window one day until it was drooping for want of water. Then weighed 372 gm. Placed in bell-jar moistened within, in twenty-four hours it had completely revived, but weighed 369.430 gm.

Or again, if a plant be used which has wilted not through too rapid transpiration, but through slower loss of water so that the soil has become dry, and if the soil be protected, it will not revive at all when sprayed and kept in a damp atmosphere. The explanation of these facts seems to be that the rate of supply of water to leaves by conduction from roots has a maximum which may be exceeded under the same conditions by the rate of loss through transpiration, and when this occurs drooping follows. To plants in this condition spraying, when it does not directly water the earth, creates a moist atmosphere which is for some time maintained by evaporation of the clinging water-drops; transpiration is thereby diminished until it is equalled and exceeded by conduction, and revival follows. But when the drooping is the result of absence of water at the roots, these being protected no revival can follow the spraying except by direct absorption through the green parts; and the fact that in such cases no revival takes place is fair evidence that absorption through the green parts cannot, to any appreciably profitable extent, occur. That the revival of drooping parts can and does follow simple diminution of too rapid transpiration without addition of water, is shown upon a large scale out of doors in gardens when hot summer days are followed by cool evenings, and still better, in the irrigated regions of the west, in both of which cases there is an evening revival of parts which drooped under the heat and brightness of the day.

So much for the popular notion. In scientific circles there has been less unanimity. The earliest experiments of importance were those of Duchartre (1861),[1] who, starting with the idea that plants absorb dew through their leaves and wishing to measure its amount, was led by his experiments to conclude that practically they do not absorb dew or mist. His trials were mainly with entire plants, and carefully made. In 1878 Boussingault published[2] the results of his studies, which were largely upon cut plants, concluding that absorption does take place through green parts. In the meantime Henslow had been carrying on independently similar studies with similar but even more positive conclusions, and these were published shortly after.[3] Sachs in his "Lectures on the Physiology of Plants"[4] gives his opinion that the "numerous

[1]Bull. Soc. Bot. de France, **4**:—.—.
[2]Ann. de Chimie et de Physique. March, 1878.
[3]Journ. Linn. Soc. (Bot.) **17**:313-327. 1879.
[4]Engl. Ed. p. 254.

researches directed to this end [i. e., absorption through leaves] have yielded no satisfactory results whatever," and that it is not proven "that any considerable quantities of water, and salts dissolved in it, are conveyed by means of the leaves of the land plants, and that the activity of the roots and of transpiration is supplemented by this means." Vines in his "Lectures"[5] devotes a couple of pages to the subject and concludes that while under special conditions such absorption may take place, "the evidence before us is insufficient to prove that the absorption of water is an important normal function of leaves." Nothing further of importance appears to have been published of late.[6]

The paper by Henslow above cited as being the latest and most positive and as well the basis of the tests to be presently described, requires some analysis here. In reviewing the work of Duchartre, he contends that the phenomena shown by a cut shoot are a safe guide to the phenomena shown by the entire plant. But it is best to quote his exact words,[7] which are these: "It is easy to prove that all the functions of a leaf *are* carried on when detached as when growing;" and again, "all that can be called injurious to a shoot when detached for experimental purposes lasting for a short time only, is that the supply of water is cut off. The shoot may become flaccid and slightly enfeebled, but in no sense are its functions impaired. And I maintain, making due allowance for that fact, whatever results a cut shoot or detached leaf gives in the matter of absorption and transpiration, they *are* [sic] legitimately applicable to a growing plant. Those who assert it to be otherwise must bear the burden of proof."[8] It is not surprising after these statements, that this writer considers the results of his many experiments upon cut shoots as applicable to normally growing plants, and that he therefore con-

[5] Pp. 65-67.

[6] In Science, July, 29, 1893, Mr. E. A. Burt publishes some notes which show that cut shoots absorb some water. He also thinks that some absorption takes place in uninjured plants at night, but his experiments do not seem conclusive on this point.

[7] Op. cit. pp. 314, 315.

[8] According to this contention, if a cut shoot could be supplied with a water supply equivalent to that which it has before cutting, it could continue to act normally in its water relationships for an indefinite period. Mere dipping in water is of course not enough, as root pressure is absent. But I have attached tubes to the cut petioles of leaves, giving them a pressure of a column of three to four feet of water, and they remain fresh but little longer than those merely placed with the cut ends in water.

cludes: "There are ample reasons for believing that dew and rain are under certain circumstances absorbed and utilized to supplement the root supply."

Whatever may be thought of the relationship of Henslow's experiments to his conclusion, this much seems to be clearly shown by the former, that cut shoots do absorb water through their green parts. Many of his experiments have been repeated with results similar to his.[9] But when very similar methods have been applied to uninjured shoots attached to their parent plants, the results (I may so far anticipate as to say) have been different; from which, together with other considerations, it seems that there is a marked *qualitative* difference between the behavior of injured and uninjured plants and parts of plants with reference to their power of absorption of water through their green parts, and that no conclusions can be safely drawn from results in the one case, as to the conditions in the other.

In order to test Henslow's conclusions, and to contribute to the settlement of this problem, I have carried out a rather elaborate series of experiments; and although the results are not so complete and positive as was hoped, they nevertheless have value in this direction.

In experimenting upon entire plants some method of preventing access of water to roots and soil is necessary. This can be conveniently done by use of dentists' rubber cloth; a comparatively small hole therein can be stretched so as to pass over the entire pot and yet shrink so as to clasp the stem above, where it can be further secured by winding with waxed thread. The folds of the rubber may then be gathered beneath the pot and tied. The result can be a water-tight isolation of the entire pot and contents, which is not necessarily injurious to the plant,[10] and this was the method used in the following experiments. Often to prevent access of water to soil in spraying, etc., the plant was laid and kept on its side. When it was needful to keep up a con-

[9] As also by Mr. Burt in the paper mentioned in foot note 6.

[10] Plants thus kept for weeks or even months have been healthy and clean at the end. On the other hand, there sometimes appeared a sudden and very marked "rubber disease." At the contact of rubber and stem, the latter would turn dark, shrink greatly and become dry. I could find no constancy in its appearance. It is worth study. All such plants were of course at once rejected. Late in the course of experiments, it was found that the rubber allows water vapor to pass through it especially when stretched, but it is believed that any error from this source cannot be great enough to materially affect the accuracy of the results.

stant supply of water both day and night to wet surfaces, it was done by connecting them by means of short ribbons of filter paper with beakers kept filled with water. All cases of comparative wetting, etc., were judged by other and disinterested persons. In all weighings allowance was made for withered leaves, etc. Some of the experiments were conducted in large Wardian cases, others in bell jars. When it was needful to keep the air in the latter saturated, it was done by use of wet sponges as well as by shallow dishes of water. Those experiments which are described below are the best from a very large number. There were a few cases in which contrary results were obtained, but in all such, some error could have (or was known to have) come in.

For convenience, the experiments were divided into four divisions:

1. Absorption from wet surfaces.
2. Absorption of water supplied in drops, as rain.
3. Absorption from a quantity of liquid water.
4. Absorption of water-vapor.

1. Do uninjured plants through their green parts absorb water from wet surfaces?

Exp. b. Strong plant of *Senecio petasites*; herbaceous, broad-leaved, 2^{ft} high, branching just above base into two nearly equal stalks. Of one stalk about half its length was wrapped with filter paper kept constantly wet. In open air of room. Second day, traces of drooping in unwrapped stem; third day, leaves drooping on both stems, slightly less on wrapped stem; fifth day, leaves much wilted on both, no discernible difference; sixth day, greatly wilted; tenth day, all leaves dry and withered and stems drooping; a disinterested person could not tell which was most wilted.

Exp. c. Three strong plants of same species of Senecio all 20–24^{in} high, in two pots previously treated alike; in the one, two plants, one single stalked, other three-stalked from near the base, in other pot single stalked plant. All three stalks of three-stalked plant were closely wrapped throughout, including even the leaf-axils, with filter paper constantly kept wet. In open air of room. Second day, no change; third day leaves showing signs of drooping in all three plants; fifth day, leaves drooping equally on all stalks; seventh day leaves all drooping and nearly equally, if any difference, somewhat less in wrapped stem; all continued to wilt and stems to droop until all were dead and no marked difference between them.

Exp. d. Two plants of *Hura crepitans* in separate pots, previously treated alike; stem of one wrapped completely with filter paper, kept wet. Other unwrapped, placed under large bell jars open at top; first day, no change, both vigorous; fifth day, lower pair of leaves drooped to wilting in each case; eighth day, leaves wilting on both, but no difference between them; tenth day, both wilting, but no marked difference, if any the wrapped stem rather more drooped; both continued to wilt until dead, but neither more rapidly than the other.

Exp. e. Three plants of *Coleus* sp?; common little-colored variety: 1 with three long internodes wrapped in filter paper kept wet; 2, unwrapped; 3, five *leaves* out of its twelve had filter paper pressed against both surfaces and kept wet. Placed in large Wardian case: third day, all drooping both leaves and stem, but less in no. 3; tenth day, no perceptible difference between 1 and 2, but from no. 3 leaves have dropped, though stem in better condition than in 1 and 2. Continued until all dead, with no marked difference between 1 and 2.

In all of the above cases, and in others not here described, the wrapped plants acted precisely as if the wet paper were not present; in other words they showed no signs of ability to "supplement their root supply" from this source. How very different is their behavior in comparison with that of Henslow's cut shoots exposed to very similar conditions!

2. Do uninjured plants through their green parts absorb water supplied to them in drops by spraying (or rain)?

Exp. f. A *Coleus* 8[in] high, allowed to dry slowly in Wardian case until drooping, i. e., through partial exhaustion of root supply; wrapped in rubber, wt. 158.310[gm]; laid on side and sprayed with water for several minutes, completely drenched; watched for two hours; it had dried and weighed 158.220[gm], and had not revived in the slightest.

Exp. g. Young *Pelargonium* dried slowly in Wardian case until leaves drooped; wrapped in rubber and laid on side and thoroughly drenched with spray; during and after drying it did not revive in the slightest.

Exp. h. Very fine young *Begonia* in small pot, with many leaves and splendid development of trichomes; wrapped in rubber, wt. 206.915[gm]; sprayed 5 min. with distilled water until drenched; left not in sunlight for 24 hours in Wardian case, wt. 204.815[gm]; again heavily sprayed as before; in two hours dry or nearly so, wt. 204.675[gm]; then placed in a saturated bell jar for three days, wt. 203.005[gm].

Exp. i. Healthy young *Begonia;* wrapped in rubber, and kept in Wardian case until it drooped slightly, wt. 179.090[gm]; sprayed thoroughly and at once put in a wet bell jar; next day, wt. 179.070[gm]: four days later, 178.250[gm] and no revival of the drooping leaves.

Exps. various. Other *Begonia*, *Coleus* and *Hura* plants, allowed to dry slowly until drooping, then sprayed until dripping with water and allowed to dry, when water was kept from the roots, always failed to revive, and when weighed always showed a loss.

It is of course true, that in any or all of these cases, very small quantities of water may have been absorbed. But it seems plain that no quantity of physiological importance could be taken by the plants from that so abundantly supplied to them. The evidence of the weights shown by the balance is of course of minor value, as transpiration might lessen the weight more than the absorbed water (if any) could increase it; but where transpiration in a thirsting plant is reduced to a minimum in a wet jar and a loss of weight follows, it seems to be certain that no absorption sufficient to be of use to the plant can occur.

3. Do uninjured plants, through their green parts, absorb from a quantity of liquid (hydrostatic) water?

Exp. j. Vigorous young *Helianthus*, 14[in] high, was allowed to droop for want of water until it bent over to the table. Its top, containing four young leaves and the bud, was allowed to dip into a basin of water, leaving two lower leaves in the air. It showed no trace of improvement and soon died.

Exp. k. Two vigorous *Helianthus* plants, each about 18[in] high, allowed to droop for want of water until they bent over in a curve to the table. The two large lower leaves of each were then placed in a basin of water while the tops with their leaves were left outside. Whole placed in Wardian case where transpiration could not be too rapid. Both plants continued to wilt until dead, the leaves in water turning yellow and soon dying also.

Exp. l. Young *Begonia* with two strong leaves, one placed in basin of water, one not; whole placed under a bell jar open at top; plant continued to wilt until it died.

On this division of the subject, the experiments are too few and inconclusive, but this is perhaps of the less importance, since such absorption could have very little opportunity to occur normally in nature. Henslow found that an uninjured plant of *Mimulus moschatus* lived for months after one of its shoots had been immersed in water, but this was plainly by virtue of the adventitious roots which it put forth.

4. Do uninjured plants, through their green parts, absorb water vapor?

Exp. m. Strong young *Pelargonium*, wrapped in rubber cloth, weighed complete 187.104[gm]; dried rapidly by current of air dried by $CaCl_2$ until in two days it weighed 181.186[gm]; then in Wardian case three days, wt. 180.135[gm]; then in wet chamber, nearly saturated; in one day wt. 179.552[gm]; in three days, 178.732[gm]; four days, 178.212[gm]; seven days, 176.830[gm]; and many new leaves appearing[11]; nine days, 175.920[gm]; continued to decrease steadily in weight for two months until it died.

Exp. n. Young but well-rooted *Coleus*, wrapped in rubber cloth, weighed 182.645[gm]; dried in open bell jar for four days, weighed 181.802[gm], drooping; placed in saturated bell jar; after one day, wt. 181.376[gm]; two days, 180.744[gm]; continued to lose weight, dropping old leaves and putting out new ones until it died.

Exp. o. Strong young *Coleus*, wrapped in rubber, all old leaves removed, plant left in Wardian case several days to recover; put out new leaves; then put in a saturated jar and it lost weight until it died. Young *Pelargonium* acted similarly.

Exp. various. Several plants died for want of water in an atmosphere saturated with it.

These latter experiments prove nothing new, but they have their value in this connection as showing forcibly that a plant may die for want of water in an atmosphere saturated with it. If the absorption of water vapor were an "important normal function of leaves" this ought not to be so rapid and positive as it is.

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[11]This was several times noticed, and is referred to by Henslow, who thinks that young leaves are a medium of absorption, and are hence put out in greater numbers when water from the air is needed. It is also worth remark that some evidence was observed indicating that when a leaf attached to its plant is injured, it may absorb water through the injury.

Of the whole subject, in summary, it may be said, that while these described experiments may appear to be too few and too imperfect to justify conclusions applicable widely to living plants under entirely natural conditions, nevertheless, made as they are upon fairly representative plants, they seem to render it very improbable that the absorption of water through their green parts is at all general or appreciable in amount among ordinary land plants. Whether in plants of special habit, with special structures which may be used for the purpose (as epiphytic Bromeliaceæ, etc.), such absorption takes place is another and distinct question, and in some cases has proved, and in others may prove, answerable in the affirmative, consistently with an equally emphatic negative for ordinary land plants.

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